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The European renewable energy target for 2030 – an impact assessment of the electricity sector

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Abstract

The European Union set binding targets for the reduction of greenhouse gases (GHG) and the share of renewable energy (RE) in final energy consumption by 2020. The European Council agreed to continue with this strategy through to 2030 by setting a RE target of 27% in addition to a GHG reduction target of 40%. We provide a detailed sectoral impact assessment by analyzing the implications for the electricity sector in terms of economic costs and the regional distribution of investments and shares of electricity generated from renewable energy sources (RES-E). According to the Impact Analysis by the European Commission the 27% RE target corresponds to a RES-E share of 49%. Our model-based sensitivity analysis on underlying technological and institutional assumptions shows that the cost-effective RES-E share varies between 43% and 56%. Secondly, we quantify the economic costs of these variants and those which would be incurred with higher shares. The long-term additional costs for higher RES-E shares would be less than 1% of total system costs. The third aspect relates to the regional distribution of EU-wide efforts for upscaling renewables. We point out that delivering high RES-E shares in a cost-effective manner involves considerably different efforts by the Member States.

Keywords: renewables, electricity sector, climate and energy policy, EU 2030 targets, effort sharing, European Union

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1. Introduction

Since 2009 the European Union (EU) has adopted an explicit target for the share of renewable energy (RE) in the provision of gross final energy consumption. This was agreed upon in the context of the “EU climate and energy package” (the so-called 20-20-20 package) that includes: (i) a 20% reduction in EU greenhouse-gas (GHG) emissions from those of 1990, (ii) raising the share of RE in the EU’s final energy consumption to 20% (including a renewable share of 10% in the transport sector), and (iii) a 20% improvement in the EU's energy efficiency. The RE target has been converted to provide mandatory national targets that differ across Member States, considering their different starting points in terms of energy mix, renewables potential, GDP and past efforts (European Union 2009). In aggregate, the share of RE has been steadily increasing; its share in gross final energy consumption rose from just above 8% in 2004 to 14% in 2012 (Eurostat 2014a).

In order to provide long-term policy targets, a continuation of the RE target was discussed within the negotiating process for a 2030 framework for climate and energy policies (Geden & Fischer 2014). In October 2014, the European Council set targets of at least 40% for domestic GHG reduction, and at least 27% for the RE share in final energy consumption (European Council 2014). In addition, an indicative target of at least 27% is set for the improvement of energy efficiency. While the Commission’s Impact Assessment has analyzed two variants of the 40% GHG reduction scenario with different combinations of energy efficiency and renewable target (European Commission 2014b), a detailed analysis of the consistency between the individual targets is missing (see Flues et al. (2014) for an analysis of the electricity sector with a stylized model). In addition, a detailed sectoral impact assessment, for example of the transport sector, the electricity sector or the agriculture sector was not part of the Commission’s analysis and is so far only rarely provided in the literature (see Enerdata (2014) for an analysis of the electricity sector).

With our analysis we close this gap for the electricity sector by providing an in-depth analysis of the share of electricity generated from renewable energy sources (RES-E) under a range of technological and institutional assumptions. We also identify the implications on economic costs and the effort sharing across the Member States. The motivation to concentrate on the electricity sector is that it already plays and will play a major role for the decarbonization effort particularly in the short-term (Knopf et al. (2013a) and IPCC (2014)): In recent years the European RES-E share increased significantly, reaching 23.5% in 2013 (Eurostat 2014b). According to the Commission’s Impact Analysis (European Commission 2014b) the energy-system wide 27% RE target is consistent with a

49% RES-E share. This considerably higher sectoral share underlines the importance of the electricity sector in delivering the overall target.

For the quantitative analysis, we utilize a refined version of the European electricity sector model LIMES-EU that was first published in Haller et al. (2012a) for an analysis of the long-term decarbonization of EU's electricity system. The modeling framework LIMES (**L**ong-term **I**nteraction **M**odel for the **E**lectricity **S**ystem) was also applied in Ludig et al. (2011, 2015) and Haller et al. (2012b). Nahmmacher et al. (2014a) provide an in-depth documentation of the modeling setup used in this analysis and Nahmmacher et al. (2014b) describe the refined approach for modeling the integration of variable renewable sources across Europe. Results in the Commission's Impact Assessment are derived from an analysis based on one single energy system model, namely PRIMES (Capros et al. 2014; E3MGLab 2011), with a limited set of alternative scenarios and is thus subject to a variety of specific model- and data-related input assumptions. In this paper we provide an in-depth sensitivity analysis of the electricity sector with LIMES-EU to assess the robustness of the results and the implications on costs and distribution. This aspect is missing in the EU Commission's Impact Assessment.

The figure of 27% for the RE share is derived from the EU Commission's own modeling analysis (European Commission 2014b). The scenario that achieves a 40% GHG reduction in 2030 results in a RE share of 26.5%. This means that, based on this analysis, a 27% share of RE is the cost-effective share when a target of 40% GHG emission reduction is set. This is an important aspect often neglected in the debate; it indicates that the renewable target of 27% does not generate any additional burden for the deployment of renewables beyond its contribution to the reduction of GHG emissions. Conceptually, it also means that in the presence of a binding CO₂ policy, for example a price on carbon, specific subsidies for renewables are only justified when other externalities such as learning spillovers exist. In this paper, we refer to this benchmark as the "cost-effective RE target", meaning the share of RE that is necessary to achieve the 40% climate target at least costs over time³. Given these conditions, the European Commission's modeling has shown that to achieve a reduction of 40% GHG emissions, it is cost-effective to deploy 27% renewables by 2030. In the months before the Council's decision there was a political debate regarding whether a separate RE target is actually necessary. In the policy arena, an additional RE target is often justified by referring to its potential co-benefits, such as employment effects, local added value, additional environmental benefits and industrial policy (Edenhofer et al., (2013); Edenhofer et al., (2013); Lehmann and Gawel (2013);

³ It also refers to the economic welfare perspective on these costs in contrast to costs seen by individual market participants. Our specific analysis only examines the electricity sector, rather than the overall economy.

Bruckner et al., (2014)), although the evidence of these co-benefits is highly disputed (Borenstein 2012). Renewable energy policy has a long tradition in Europe: back in 1986 the promotion of renewables was one of the Community's energy objectives (Kanellakis et al. 2013). The European Commission explicitly states that "increased shares in renewables [...] contribute to more indigenous energy sources, reduced energy import dependence and jobs and growth" (European Commission 2013b). The EU Council conclusions define an "at least" 27% RE target, implying that a higher target might be possible if individual Member States set their own national targets at a higher level. If this is the case, and the RE share is meant to be higher than that which is cost-effective, we postulate that the underlying rationale is based on considerations other than climate change mitigation. However, in the official analysis there is no quantification of the costs of a RE target which is additional to that for GHG reduction.

For the electricity sector, our modeling framework can provide an analysis of the cost-effective RES-E share given an exogenously specified long-term decarbonization pathway. Within our optimization framework, a RES-E share that is forced to be higher than the cost-effective share always leads to additional costs. These costs can, in principle, be weighed against the expected co-benefits. In this paper we compute the additional costs for a higher than cost-effective RES-E share, being one side of the equation of the political debate. The quantification of potential co-benefits is beyond the scope of the paper.

A further aspect we highlight is that, although the effort to achieve the GHG target is incorporated into nationally binding targets at individual Member State level for the sectors not covered by the European Emissions Trading Scheme (ETS), the RE target needs to be "delivered collectively" (European Council 2014). In their Energy Union Package of March 2015 the EU Commission states that they will "propose a new Renewable Energy Package in 2016-2017 including [...] legislation to ensure that the 2030 EU target is met cost-effectively" (European Commission 2015). An EU-level target might be difficult to achieve as although some form of governance mechanism is anticipated (European Commission 2014a), Europe is rather politically divided over the importance of a renewable target at all (Evans 2014) and yet there is no explicit effort sharing rule designed to achieve the RE target at the EU level. We analyze the cost-effective distribution of the RES-E share across the Member States and draw some conclusions concerning the infrastructure requirements, import/export balances and European effort sharing on renewable deployment.

In summary, this paper provides an impact assessment of the electricity sector and draws conclusions on the following key research questions in order to inform the political debate:

1. What is the cost-effective RES-E share in the year 2030 that is consistent with a long-term decarbonization pathway until 2050, given variants of key technology and institutional input assumptions? Which RES-E technologies make important contributions?
2. What are the economic costs of these variants and those of a RES-E share enforced to be higher than the cost-effective one?
3. What does the setting of the RE target at the European level (rather than at Member State level, as for 2020) imply for its distribution across countries? What would cost-effective effort sharing look like? Which countries are likely to contribute most to the overall RES-E provision?

The remainder of this paper is structured as follows. The method of the analysis is illustrated in Section 2, introducing the model LIMES-EU (Section 2.1) and the scenario setup (Section 2.2). We present and discuss the modeling results in terms of sensitivity analysis, costs and regional distribution in Section 3. Section 4 concludes and derives policy implications.

2. Method

2.1. The electricity system model LIMES-EU

The European electricity system model LIMES-EU (Nahmmacher et al., (2014a,b), Haller et al., (2012a) is designed to generate quantitative scenarios that represent a consistent, system-cost optimal transition towards a decarbonized European electricity system in 2050. In its current version the partial equilibrium model comprises 26 of the 28 EU Member States⁴ plus Norway, Switzerland and the Balkan region. The capacities of generation and storage technologies are aggregated nationally, with each country constituting one model region⁵. The transmission grid in LIMES-EU is represented by Net Transfer Capacities (NTCs) between the model regions. Electricity exchange with regions outside the modelled area is not possible. The model is calibrated to the base year 2010, for which installed power generation and storage capacities are fixed according to Platts (2011) and Eurostat (2013b). The installed transmission network is reflected by the NTC summer values of 2010 as reported by ENTSO-E (2013).

⁴ The island states of Malta and Cyprus are not included in the current model version

⁵ with the exception of the non-EU countries in the Balkan region that are grouped to one model region

Endowed with perfect foresight, LIMES-EU yields a social planner solution that optimizes the following features in time steps of 5 years for each model region: (i) dispatch and curtailment of installed electricity generation technologies, (ii) electricity import balance between neighboring model regions, (iii) investments into installed capacities of electricity generation technologies and (iv) investments into NTCs between model regions. Specified as a linear optimization model, the objective function of LIMES-EU is to minimize the total discounted⁶ electricity system costs (comprised of fuel, investment, fixed and variable operation and maintenance costs) of all model regions between 2010 and 2050. It assumes an exogenous demand for electricity and a number of technological and political boundary conditions, for example nuclear phase-out in certain Member States. Climate policy is simulated by constraining annual CO₂ emissions (see following Section for individual scenario setups).

A new time-slice approach was developed to account for fluctuating feed-in of variable renewable electricity (vRES-E) and differences in electricity demand occurring on time scales that require higher than annual resolution (Nahmmacher, Schmid, Hirth, et al. 2014). It is designed to reflect: (i) the annual electricity demand and average vRES-E capacity factors for each region, (ii) the region-specific load duration curves of electricity demand and vRES-E technologies, and (iii) the spatial correlation of electricity demand and vRES-E supply across regions. Nahmmacher et al. (2014) present the details of this procedure and show that a total of 48 time slices are appropriate to model the crucial features of vRES-E generation in Europe with LIMES-EU. It appears that spring and fall days can be represented in similar time slices and fewer time slices are required for summer days than winter days because there is less variation. With this computationally efficient method we are able to give an appropriate representation of vRES-E within Europe, which is crucial when analyzing potential RES-E shares for the year 2030.

In this modeling framework it is clear that an exogenously enforced RES-E share that is higher than the cost-effective RES-E share will always lead to additional costs. This is because LIMES-EU is an intertemporal optimization model endowed with perfect foresight that takes into account only the climate externality – in such a framework additional bidding constraints always lead to additional costs. The aim of the analysis in Section 3.2 is to quantify these costs. It should also be clearly stated here that, in this model setting, we can neither explore potential co-benefits nor address other externalities resulting from RES-E deployment. This includes learning and spillover externalities or externalities at the diffusion site.

⁶ We apply a social discount rate of 5%.

2.2. Scenario setup

We deploy a large number of scenarios to assess the robustness of the 49% RES-E share in 2030 with respect to technological, institutional and policy parameters and settings. Except for the “low GHG target”⁷ scenario, all scenarios are required to meet the same CO₂ reduction pathway until 2050. The pathway is designed according to the “Roadmap for moving to a competitive low carbon economy in 2050” (European Commission 2011), which suggests a strong decarbonization of the electricity system by 2050 with an emission reduction of about -95% compared to 1990. The intermediate annual emission limits are decreasing linearly between 2010 and 2050, resulting in a 52% reduction by 2030 compared to 1990. For all scenarios these emission reduction requirements in the electricity sector are applied as boundary conditions. In order to be comparable with the Impact Assessment (European Commission 2014b), we configure our “default scenario” with techno-economic and policy assumptions similar to its scenario “GHG40”. We also provide an in-depth sensitivity analysis of the electricity sector that is not part of the EU Commission’s Impact Assessment. The parameters we vary include nuclear and carbon capture and sequestration (CCS) policy, biomass availability, wind and solar cost development, transmission capacity, electricity demand, electricity storage capacity, and transmission capacity. In addition, we evaluate scenarios with a higher than cost-effective RES-E share and one scenario with a lower level of emission reduction. See Table 1 for an overview.

The following paragraphs substantiate the chosen variants and describe how they drive the model.

Nuclear power is a heavily disputed source of electricity in Europe. As a default assumption, we implement a nuclear phase-out in Germany, Belgium and Switzerland. New installations in other countries are limited to those currently under construction or planned⁸, or those required to replace depreciated capacities. Whether nuclear power will be part of the European electricity mix of the future is ultimately a political decision. In order to evaluate the implications of a nuclear-phase out across Europe we consider two scenarios. One assumes a complete nuclear phase-out in each modelled country by 2030 (NucOut 2030). The other scenario assumes a reduction of 50% of today’s national nuclear capacities by 2030 and a phase-out by 2050 (NucOut 2050).

⁷ The “low GHG target” scenario is based on the reference scenario of the European Commission (2013) with only 44% overall GHG reduction by 2050, with power sector CO₂ reductions at about 73% by 2050.

⁸ According to the World Nuclear Association (2013) new nuclear capacities under construction or planned are: Belgium (1.9 GW), Czech Republic (2.4 GW), Finland (1.7 GW), France (3.44 GW), Great Britain (3.8 GW), Lithuania (1.35GW), Poland (6 GW), Romania (1.31 GW) and Slovakia (0.88 GW).

Table 1: Overview of scenarios

	Technology / Institution	Issue	Scenario Name
	Default scenario as in “GHG40” of the Impact Assessment by the EU Commission (2014b) and as agreed by the European Council (2014)		default
Technology setting	Nuclear Power	Phase-out until 2030	NucOut 2030
		Phase-out until 2050 (-50% in 2030)	NucOut 2050
	CCS	Not available	NoCCS
	vRES-E (wind, solar)	Higher investment costs (+10% in 2020; +20% in 2030 and thereafter)	high cost vRES-E
		Lower investment costs (-10% in 2020; -20% in 2030 and thereafter)	low cost vRES-E
		Only sites with average capacity factors	low pot vRES-E
	Storage	Higher investment costs (+100%)	high cost stor
Biomass	Higher fuel costs (+100%)	high cost bio	
Institutional setting	Transmission capacity expansion process	No capacity expansion beyond today, completion of internal market impeded	no trans exp
		Faster capacity expansion / market integration (expansion rate +100%)	high trans exp
	Energy security concerns	More than 95% of electricity supply from domestic power plants	95% national
	Success of energy efficiency programs	Electricity demand lower by 5% in 2030 and thereafter	demand -5%
		Electricity demand lower by 10% in 2030 and thereafter	demand -10%
Policy ambition	minimum 55% RES-E share in 2030 and thereafter		RES-E 55%
	minimum 60% RES-E share in 2030 and thereafter		RES-E 60%
	minimum 65% RES-E share in 2030 and thereafter		RES-E 65%
	Reference scenario of the European Commission (2013) with only 44% GHG reduction by 2050 (instead of 80%)		low GHG target

The question of whether it will be legally possible to deploy CCS facilities in Europe is likewise a political choice. Whether it will be economically viable is ultimately a question of technology cost

developments. In the default scenario we allow CCS for the combustion of lignite, hard coal and natural gas; consult Table A.2 in the Appendix for the techno-economic parameters. The scenario NoCCS assumes that political and technological hurdles related to the deployment of CCS across Europe cannot be overcome (compare von Hirschhausen et al., 2012).

It is highly uncertain how investments cost and storage solutions for the vRES-E technologies (onshore and offshore wind, solar photovoltaic (PV) and concentrated solar power (CSP)) will develop over the coming decades. In the default scenario we use the same vRES-E investment costs as in the Impact Assessment (European Commission 2014b) (see Table A.1 in the Appendix). The high (low) cost vRES-E scenario assumes that investment costs of vRES-E technologies will develop less (more) favorably. A separate scenario (high cost stor) evaluates the impact of storage solutions being more capital-intensive than assumed in the default setting (see Table A.2 in the Appendix).

A further parameter that is uncertain but crucial is a country's wind and solar power technical potential. In LIMES-EU it is a function of the installable capacity of wind and solar power plants, which depends on each country's size and land structure as well as the achievable capacity factor at each site. Details of our assumptions for deriving the vRES-E potential are provided in Nahmmacher et al. (2014) and (2014). In order to reflect the circumstance in which the useable wind and solar power potential is lower than anticipated, for example due to lower social acceptance of wind power plants or other empirically observed factors (Boccard, 2009), we calculate one scenario using solely average capacity factors (low pot vRES-E).

The biomass potential incorporated in LIMES-EU is based on data from EEA (2006) which gives the environmentally-compatible bioenergy potential from agriculture, forestry and waste. We assume that one third of the potential stated in EEA (2006) is eligible for electricity production in LIMES-EU as not all of the total biomass potential can be deployed at competitive prices and the transport and heat sector also utilize a considerable amount of the available biomass stock. Where the potential calculated for a specific country⁹ is smaller than its biomass deployment target stated in the National Renewable Energy Action Plans (NREAPs) (European Commission 2013c), the potential is increased to meet the target¹⁰. The default scenario's biomass and fossil fuel prices are stated in Table A.3 in the Appendix. In order to evaluate the impact of higher fuel prices for biomass we consider one scenario in which they are doubled (high cost bio).

⁹ Biomass potentials of countries for which no data is available in EEA (2006) are calculated based on the extent of arable land and forests (FAO 2013) as well as the land structure and biomass potential of the surrounding countries with available data.

¹⁰ This is the case for Belgium, Denmark, Luxemburg and the Netherlands.

In addition to the technology variants, we analyze scenarios that represent different institutional settings. An important factor is the speed and degree to which transmission capacities can be expanded beyond today's performance level (Schmid & Knopf 2014). The default annual expansion of cross-border transmission capacities is restricted to 0.2 GW of net-transfer capacity (NTC) per cross-country connection. This constraint serves as a proxy for the limit on the achievable speed of capacity expansion, which may be imposed, for example, by social or bureaucratic considerations. We consider two extreme variants to represent a slower, more nationally focused situation and a faster, decisive integration of the European electricity market; one scenario does not allow for any transmission capacity expansion beyond today's level (no trans exp), while the other allows a doubling in the upper limit of capacity expansion to 0.4 GW per year of net-transfer capacity (NTC) per cross-country connection.

Further institutional issues are energy security concerns and energy efficiency. Regarding the first we implement a scenario in which each country has to supply 95% of electricity from domestic power plants (95% national), i.e. net imports of each model region must not exceed 5% of domestic electricity consumption. To provide a proxy for successful energy efficiency programs we reduce the annual electricity demand of the default case by 5% (10%) in 2030 and thereafter, in the demand-5% (demand-10%) scenario. The default assumptions for future electricity demand are reported in Nahmmacher et al. (2014). Final electricity demand in the model's calibration year 2010 is retrieved from Eurostat (2013a) and IEA (2012). Demand projections up to 2050 are taken from the projections of the European Commission (2014b). For regions not included, demand growth rates are estimated based on the growth rates of their neighboring countries for which data is available

Finally, we consider the pursuit of a less ambitious mitigation policy ("low GHG target") – as reflected in the European Commission's reference scenario. This assumes GHG emission reductions of 32% by 2030 and 44% by 2050 (European Commission 2013a). This is the equivalent of a 41% CO₂ emission reduction in the electricity sector by 2030 and 73% reduction by 2050.

In order to investigate variants of the default scenario in which a higher than cost-effective RES-E share is set for 2030 we consider scenarios that have an imposed share of 55%, 60%, and 65% in that year (see the bottom of Table 1). In these model runs, a constraint enforces the RES-E share to remain at least at this level from the year 2030 onwards.

3. Results and Discussion

3.1. Sensitivity analysis of the cost-effective RES-E share

This section determines the cost-effective RES-E share and technology mix for the European electricity sector in 2030 according to the LIMES-EU model. Figure 1 shows the results of the extensive sensitivity analysis for the respective technology mix of RES-E in the year 2030 (for overall electricity generation see Figure A.1. We identify three main findings.

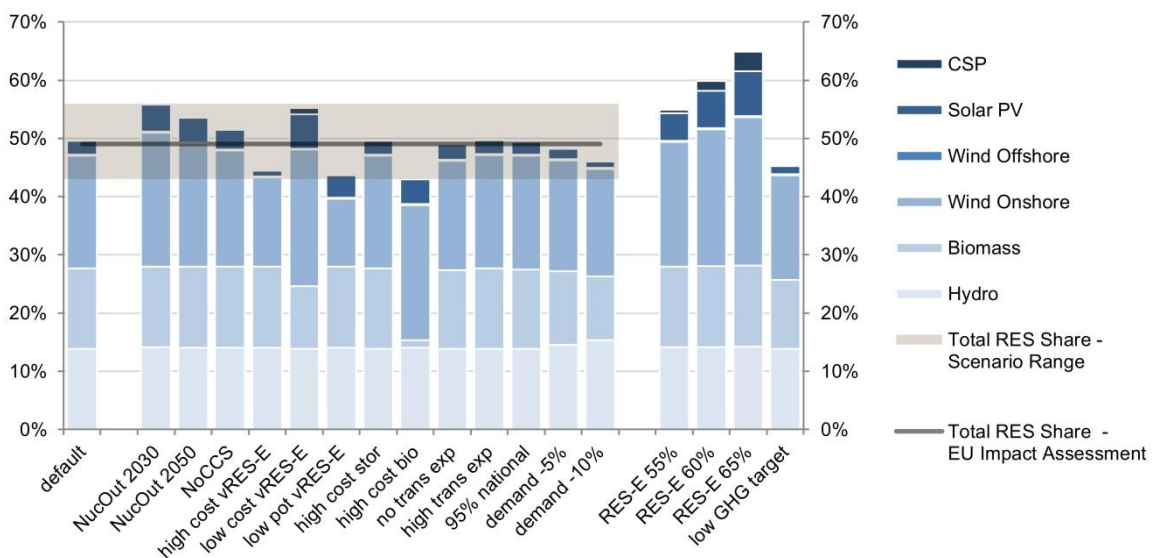


Figure 1. Share of renewables in the European electricity sector in percent of total electricity provision and the respective technology mix of renewables in the year 2030. Gray shading indicates the range across scenarios. Source: Model results of LIMES-EU. Black line: Share of RES-E in the electricity sector in the scenario “GHG40” of the Impact Assessment for the 2030 framework by the European Commission (2014a), 49%.

First, with LIMES-EU we find that the default scenario results in a RES-share of 50% in 2030. This is very close to the cost-effective RES-E share of 49% identified by the European Commission (2014b) in the scenario “GHG40”. This implies that our analysis can be seen as a proxy for the sensitivity analysis which is missing from the PRIMES model used in the Impact Assessment.

Second, our sensitivity analysis suggests that the cost-effective RES-E share ranges from 43% to 56%, which seems quite narrow given that some of the assumptions are rather extreme. The 49% from the Impact Assessment lies right in the middle of this range. As expected, the cost-effective share is higher when nuclear or CCS are constrained or investment costs of vRES-E technologies are reduced.

In contrast, the cost-effective share is lower when the investment costs of vRES-E technologies are higher, their technical potential is restricted, biomass costs are higher or electricity demand is lower than in the default case. Notably, high storage costs and all institutional assumptions have virtually no influence on the cost-effective RES-E share in 2030. Even in the scenario “low GHG target”, with only 41% rather than 52% CO₂ emission reduction against 1990, the cost-effective RES-E share of 45% is within the range spanned by the sensitivities. This implies that the optimal RES-E share depends more on other uncertain input assumptions and political factors than on the overall level of emission reduction.

The third finding concerns the technology-specific uncertainty. The technology mix that emerges for 2030 is similar across all scenarios, especially for hydro and biomass. The exception is the scenario which has high costs for biomass: this has a much smaller share of bioenergy (high cost bio). In contrast, the share of vRES-E (wind and solar PV) varies considerably: between 16% and 31% (22% in the default case). This suggests there are likely to be challenges in terms of system integration, but according to IEA (2014) they seem manageable with current levels of system flexibility. Onshore wind plays a very important role in all scenarios, although its share is reduced if high quality wind sites are unavailable (low pot vRES-E) or investment costs are higher than expected (high cost vRES-E). In the scenarios in which the share of biomass is low, the difference is satisfied with a higher share of wind. Solar PV is only used to a limited extent in all of the scenarios. However, in the scenarios with the highest total RES-E share (NucOut 2030, low cost vRES, NucOut 2050), the share of solar PV is also at its highest. Concentrated solar power (CSP) does not play an important role in any of the scenarios; this technology has comparatively high costs of production in the year 2030 and is hence not deployed. CSP is only deployed in the scenario with optimistic investment cost developments (low cost vRES-E). Offshore wind is the only RES-E technology that plays an even less important role than CSP. This is primarily due to its comparatively high costs of electricity generation, relative to those of the more mature technologies onshore wind and solar PV. Future investment costs are projected to remain constant or maybe even increase (Heptonstall et al., 2012); activities for bringing down investment and particularly O&M costs are underway but show slow progress (Kaldellis and Kapsali, 2013) .

In the scenarios with a higher than cost-effective share of RES-E, the additional investments into RES-E capacities between 2025 and 2030 primarily consist of solar PV and onshore wind. Also, CSP increasingly comes into play. Offshore wind is again not deployed in these scenarios, due to the prohibitively high investment costs assumed in the “GHG40” scenario of the Impact Assessment by the European Commission (2014b), which we proxy with our default scenario. The level of hydro and

biomass is unaffected by the prescribed RES-E share in 2030. Upon a closer look on the development over time, they follow the same path until 2025. Between 2025 and 2030 investments in RES-E capacities are pursued as necessary to fulfill the target in 2030. Thereafter, the RES-E share stagnates over time, in all scenarios, until it meets the cost-effective trajectory for achieving the 95% mitigation target in 2050.

3.2. Economic Costs

The objective function of LIMES-EU is to minimize the present value of cumulative discounted total system costs over the period 2011-2050. Hence, this is the primary indicator for analyzing the economic costs of the different scenarios¹¹. Figure 2 illustrates the differences in the present value of cumulative costs between the variants and the default scenario, for the two periods 2011-2030 and 2011-2050. It is important to take the intertemporal aspect into account, as renewables require high upfront investments but generate long-term savings in fuel costs.

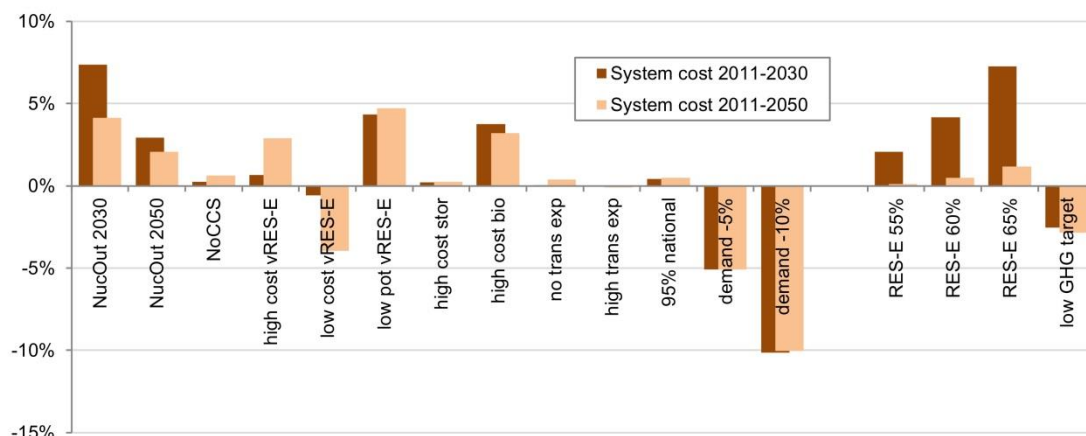


Figure 2. Percentage difference in total discounted system costs for the different scenarios relative to the default scenario for two different time spans (2011-2030 and 2011-2050). Source: Model results of LIMES-EU.

Several observations are noteworthy. First, the cost differences across the variants are much higher than the difference between the default scenario and the scenario with less ambitious emission reductions (low GHG target). Second, the two most potent factors for decreasing total discounted system costs are: (i) lowering the investment costs for variable renewables and (ii) reducing electricity demand. Third, the magnitude of the differences in the economic costs of setting the RES-E share above the cost-effective share of 50% is comparable with the uncertainties resulting from

¹¹ If not mentioned otherwise, all prices and costs stated in this paper are measured in €₂₀₁₀

different input assumptions. It is obvious that the costs increase with the level of ambition of the target. The additional costs for the higher RES-E shares however, are only noticeable in the period up to 2030. In the long-run, i.e. up to 2050, the additional costs are up to 0.9% (30 bn€) higher than that of the default scenario for a RES-E share of 65% in 2030. This is different to the NucOut 2030, low pot vRES-E and high cost bio scenarios, where the costs are high in both the medium-term to 2030 and long-term to 2050; they are nearly 4% higher than in the default setting.

The reason that the additional costs for a RES-E share higher than the cost-effective one are small for the period 2011-2050 (compared to those for the period 2011-2030) is that in the long-term a system with a high share of renewables saves fuel costs as shown in Figure 3. In LIMES-EU, total system costs consist of investment costs, operation and maintenance (O&M) costs and fuel costs. Figure 3 shows the relationship between each of these individual components for the scenarios with higher RES-E shares and the default scenario, for the periods 2011-2030 and 2011-2050. It shows that the largest proportion of costs are investment costs. These are nearly 50% higher in the “RES-E share 65%” scenario for the period 2011-2030 than the default scenario which does not have an additional RES-E constraint. However, in the long-term, up to 2050, these additional investment costs amount to just 10% above those in the default scenario. This is because in order to meet the higher RES-E share in 2030, substantial investment is required between 2025 and 2030, which tails off afterwards. It is important to acknowledge that investment costs are different to fuel costs, as they have the ability to stimulate economic development (Creutzig et al. 2014), for example through a multiplier effect. In contrast, fuel costs can constitute a cash outflow from the economy, if purchased from abroad. This is largely the case for fossil fuels in Europe. Also, investment costs are certain once they are incurred while future fuel prices are subject to significant volatility.

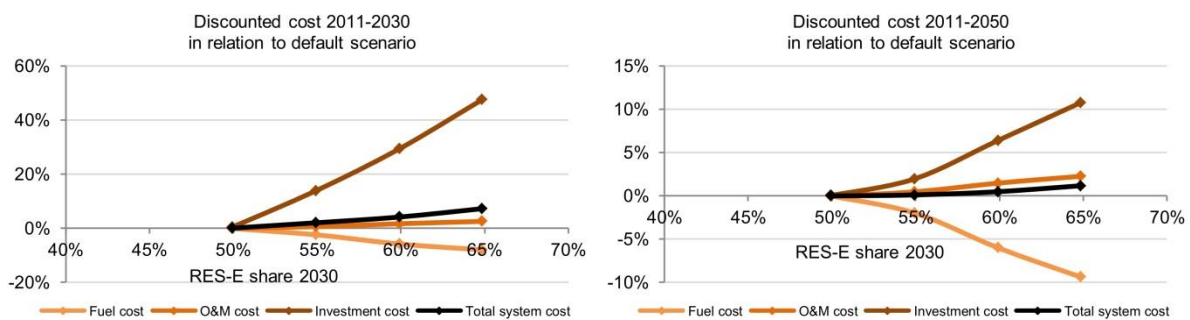


Figure 3. Discounted costs over the period 2011-2030 (left) and 2011-2050 (right) for scenarios with different exogenously enforced RES-E shares from 2030 onwards, shown in percentage terms relative to the default case with an endogenous RES-E share in 2030. Given are the different cost components of the total system costs: fuel costs, operation and maintenance (O&M) costs and investments costs. All scenarios have the same emission reduction target. Source: Model results of LIMES-EU.

Relatively high shares of RES-E lead to a substitution of electricity generation based on fuel-cost-intensive technologies and hence to a reduction in fuel costs. In the case of LIMES-EU, this particularly leads to a lower share of gas powered plants. Hence, the fast deployment of RES-E capacities by 2030 leads to fuel cost savings, and therefore lower total system costs, in the years between 2030 and 2050. The effect of the higher than cost-effective RES-E shares on operation and maintenance costs is comparatively moderate. Overall, the relative cost increase stemming from substantially higher investment costs for RES-E capacities up to 2030 and moderately low increases in operation and maintenance costs is counterbalanced by subsequent low fuel costs. Such costs are expected to reduce by roughly 14% for the period 2011-2050. Hence, the longer the time-perspective, the lower the additional costs for a higher than cost-effective RES-E share.

Another way of looking at the costs for higher RES-E shares is to calculate the shadow price of the RES-E constraint. This shadow price indicates how much the total system costs would increase with each additionally enforced MWh of RES-E generation. This increase is linear and to reach 65% renewables by 2030, a shadow price of almost 75 €/MWh for RES-E-based electricity is reached. Note that in the 60% and 65% scenarios, the respective RES-E constraint leads to such a high deployment of RES-E capacities that the CO₂ emission pathway becomes a non-binding constraint. Hence, the shadow price of CO₂ emissions decreases to zero in this case.

In principle, these economic costs could be balanced against potential co-benefits, for example employment effects or health benefits, of additional RES-E deployment. According to the IPCC (2014), co-benefits refer to “positive effects that a policy or measure aimed at one objective might have on other objectives, without yet evaluating the net effect on overall social welfare”. However, this calculation is not straightforward and there are only few attempts found in literature (McCollum et al. 2013). Most approaches have considerable methodological shortcomings and it is important to realize that co-benefits are ignored in the model used in the European Commission’s quantitative analysis; only the climate mitigation target is considered endogenously. The main reason for this is because most existing energy system models are incapable of representing the underlying processes of co-benefits of RES-E in sufficient detail. Instead, in the Impact Assessment (European Commission 2014b) an accounting of co-benefits is derived *ex-post* using other models that also face some conceptual shortcomings (Knopf 2014).

3.3. Analysis of the regional distribution

The 2030 target for renewables is formulated in order to deliver the overall RES-E deployment at EU level. However, the contribution required by each Member State remains unresolved. A number of analyses have indicated that the regional distribution is especially important, taking into account the aspect of a *fair* effort sharing within the EU (Boratyński et al. (2014), Enerdata (2014)). For GHG emission reduction in the sectors not covered by the European Emissions Trading System (EU-ETS), the individual countries' reduction efforts will be distributed on the basis of relative GDP per capita (European Council 2014). For the renewables in the electricity sector the NREAPs apply until 2020 and specify national RES-E targets based on RES-E shares in 2005, renewables potential, GDP and past efforts (European Union 2009). For the 2030 target however, the regional distribution of the RES-E share remains unresolved, except that different levels of ambition are clearly expected for different Member States. Our results show the cost-effective effort sharing required between Member States to achieve the overall target.

Figure 4 (left) shows the individual countries' RES-E share in 2030. As the resource potential is quite different across the countries, it is not surprising that individual Member States contribute quite differently towards the overall target. For example, Norway has a high RES-E share due to hydro, while in France, where nuclear plays a large role, the share is smaller. It also shows that the diversity in electricity mix across Member States is substantial and even increases towards 2030 (see also Knopf et al., (2013b)).

The right panel indicates that this scenario comes with a significant expansion of net transfer capacities across Europe which are particularly strengthened in central-Western Europe (between France, Germany, Belgium, Luxemburg). The connections to southern Europe and between Great Britain and Ireland as well as between the Baltic and Nordic states are also reinforced. The countries indicated in orange (blue) will turn into net importers (exporters). The Baltic States and Denmark will export renewable electricity generated by newly installed wind turbines. These results indicate that it is highly reasonable to combine the formulation of the RE target in 2030 with an explicit infrastructure package.

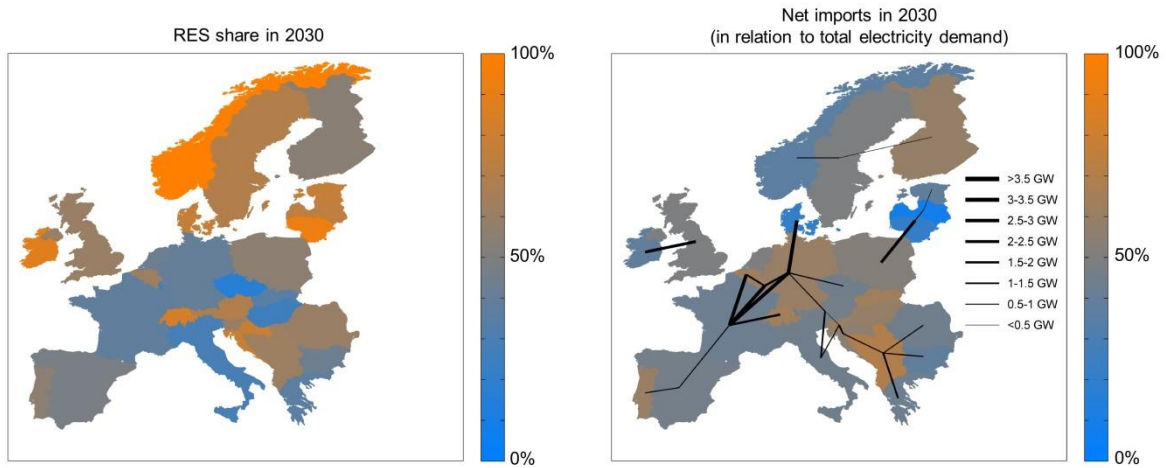


Figure 4. Share of RES-E in electricity generation for the year 2030 (left) and additional transmission capacities installed between 2011 and 2030 and the export/import balance (right) for the default scenario. Source: Model results of LIMES-EU.

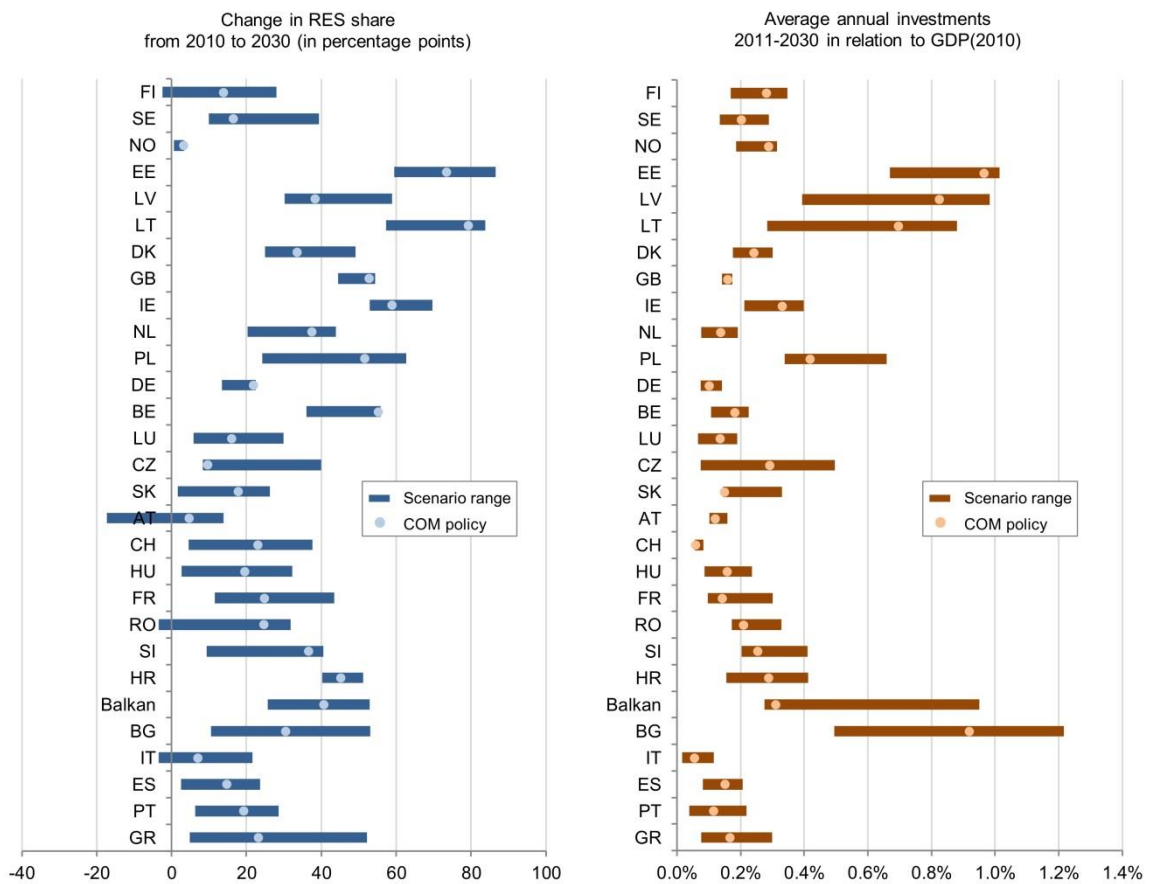


Figure 5. Percentage change in RES-E shares as a proportion of electricity production (left) and average annual investments in RES-E capacities over the period 2011-2030 compared to each country's GDP in 2010 (right). The range displayed is as implied by the technology and institutional variants, the default scenario and the RES-E share scenarios. The scenario range refers to Table 1. Member States are ordered from north (top) to south (bottom). Source: Model results of LIMES-EU.

Given that the status-quo of the RES-E share differs considerably among the different Member States with some having a high share already today, it makes sense to examine the percentage increase required to upscale renewables in the timeframe between 2010 and 2030 (Figure 5, left). It is important to note that the effort is quite diverse across Europe with some countries upscaling by nearly 80 percentage points between 2010 and 2030, while other countries only show an increase of 10 percentage points. For those countries that already provide a high share of renewables, for example Norway or Sweden, little upscaling effort is required (or possible), but countries with a much smaller RES-E share (e.g. Poland, the Baltic countries or Great Britain) have to make considerable investments in RES-E in order to achieve the overall GHG reduction target. In general it seems that the countries in the north (upper part of the figure) have to contribute more than southern countries to the overall provision of renewable deployment. This is strongly related to the finding in Figure 1 that wind is the most important future renewable electricity source in LIMES-EU.

While the left panel of Figure 5 provides an impression of the technical transformation required for each Member State, the right panel illustrates the RES-E capacity investment needed as a proportion of each country's GDP in 2010. This indicates the economic transformation requirement. For most countries, the investment requirement is much lower than 0.5% of their GDP regardless of scenario. There are, however, some exceptions: the Baltic States (Estonia, Latvia, Lithuania), Poland, the Balkan region and Bulgaria indicate investment requirements ranging from 0.5 – 1% of their GDP. This diversity across Member States is a problem that has to be addressed by an appropriate governance structure and effort sharing mechanism. Such a governance mechanism needs to take into account: (i) the different starting positions, (ii) the different RES-E potentials, and (iii) the different investment cost requirements as a proportion of GDP.

It should be noted that this analysis only gives the cost-effective benchmark for the distribution of effort. Europe is, however, rather divided over the importance of renewables and some of those countries that could in principle – according to the model results – provide a high share of renewables, for example Poland, are opposed to binding and ambitious renewable targets. In that sense, a fair effort sharing could help to bring the transformation more in line with the cost-effective benchmark.

4. Conclusions and policy implications

In October 2014 the European Council agreed on the headline targets for 2030 with domestic GHG reductions of at least 40%, a binding EU wide target of at least 27% renewables and an indicative

target of 27% energy efficiency. Based on an extensive modeling analysis of the European electricity sector, we address three major questions that arise in the context of setting a renewable target for 2030 debated in the political arena: (i) what is the cost-effective RES-E share for the year 2030 that is consistent with a long-term decarbonization pathway until 2050? (ii) what are the economic costs of setting RES-E shares higher than the cost-effective one? (iii) what does the formulation of the RE target at the European level (rather than Member State level, as for 2020) imply for the distributional question?

In brief, the answers to these questions are: (i) the RE target of 27% is the cost-effective share in line with 40% GHG reduction; this RE target corresponds to a RES-E share of 49% in the electricity sector. Our model-based sensitivity analysis shows that the cost-effective RES-E share for the long-term decarbonization of the electricity sector varies between 43% and 56%, (ii) the costs for a higher than cost-effective target are less than 1% of total discounted system costs over the period 2011-2050, but (iii) the distributional question and the missing governance mechanism for the EU-wide target might render the achievement of the target very difficult.

Based on our analysis we can conclude that an exogenously enforced RES-E share that is only slightly above the cost-effective one will not incur large additional costs. However, a target with a strong emphasis on RES-E deployment has notable implications on the overall system costs. This is particularly the case for the period 2025-2030, when substantial funding needs to be provided for deploying the required RES-E generation capacities. This analysis cannot answer the question of whether or not it is reasonable to set an additional renewables target. However, our results emphasize that there are large uncertainties in future price developments, institutional settings and the availability of technologies such as nuclear or CCS. These uncertainties have been taken into account in our sensitivity analysis. It turns out that these uncertainties increase the costs in a similar order of magnitude as a RES-E share that is higher than the cost-effective one.

Our analysis has important policy implications on infrastructure planning and on a governance mechanism for achieving the EU-wide RE target:

- While the focus is often only on the deployment of renewables, the required pan-European transmission grid expansion is also affected by the RE target. Cross-border effects are particularly noticeable in the renewables electricity sector; for example some countries will become considerable exporters or importers of electricity. In this respect, renewable deployment cannot be disentangled from infrastructure planning. The current version of the Ten-Year Network Development Plan details network reinforcements based on two RES-E

capacity visions in 2030, which essentially represent an aggregate of country-specific bottom-up plans (ENTSO-E 2014a). However, future versions should also consider a more common and cost-effective solution across Europe (ENTSO-E 2014b). A more dedicated and transparent analysis of the distributional question in the context of pan-European network planning is highly recommendable. At best, these processes should be intertwined with the regionalization of the 2030 RE target; the EU-wide target could, for example, be broken down into targets for specific regions. In addition, it would seem reasonable to develop a dedicated infrastructure package that accompanies the RE target.

- A new aspect in the EU framework for 2030 is that the RE target is only defined at EU level, in contrast to the framework for 2020 where national renewable deployment plans had to be provided by each Member State (EEA 2012). Our analysis shows that the upscaling effort required to produce renewables is quite different across the Member States. In order to accommodate these differences, one idea could be to install a financial effort sharing mechanism. As no Member State has an individual obligation to provide renewables however, it is unlikely that countries would be willing to pay for the upscaling of RES-E deployment in other Member States. An effort sharing framework for achieving the RE target would also have to consider the co-benefits that are associated with the deployment of renewables. Such a framework might be different from that required for emission reduction. In the latter case a global public good is produced (decreased risk of impacts from climate change), while the production of renewables also generates a local public good through the provision of co-benefits.

To conclude, although model results provide a clear indication that the overall RE target seems to be achievable, in political reality it is unclear which kind of governance mechanism will be able to deliver the target of 27%. The model assumes an exogenous enforcement of policies, but it is not clear whether this will be seen in reality. Some argue that an important aspect of a RE target is to foster coordination (Klinge Jacobsen et al. 2014). Given the observation that achieving the 20% renewables target by 2020 will be difficult however (European Commission 2013d), there is a clear danger that the 27% target for 2030 will not be met if no governance mechanism is installed that ensures a fair effort sharing, taking into account infrastructure requirements. Alternatively, it is possible that the target will be met, but only through efforts in countries where renewables are strongly supported by local policy instruments, e.g. in Germany or Denmark. In the end, this solution would be far from cost-effective and would render climate and energy policy in Europe very costly.

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Appendix

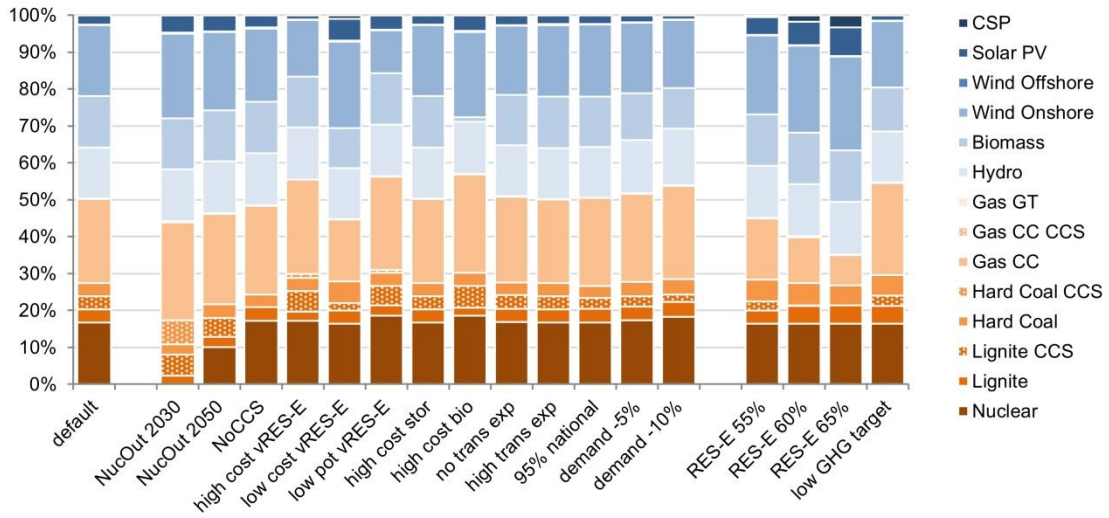


Figure A.1. Electricity generation in the year 2030 for the different scenarios under investigation. Source: Model results of LIMES-EU.

Table A.1. Investment costs for vRES-E technologies in €/kW. Source: European Commission (2014b)

	Solar		Wind	
	PV	CSP	onshore	offshore
2010	2500	5500	1300	4750
2015	2004	4329	1296	4412
2020	1508	3158	1291	4073
2025	1297	2859	1262	3790
2030	1085	2560	1232	3507
2035	1011	2411	1212	3338
2040	937	2262	1191	3168
2045	862	2112	1171	2999
2050	788	1963	1150	2829

Table A.2. Techno-economic characteristics of thermal technologies and storage solutions. Source: Schröder et al. (2013), European Commission (2014b), Haller et al. (2012), Schmid et al. (2012) and own assumptions.

Technology	Investment cost €/kW	Efficiency new (old) %	Annual availability %	Fixed O&M cost % of inv. cost	Variable O&M cost €/MWh	Lifetime years
Nuclear	4000	33	80	3	2.8	60
Hard Coal	1500	44 (37.4)	80	2	6.85	50
Hard Coal CCS	2600	38	80	2	11.42	50
Lignite	1800	43 (36.6)	80	2	9.13	50
Lignite CCS	3000	37	80	2	14.6	50
Gas CC	800	60	80	6	0.525	40
Gas CC CCS	1600	52	80	6	5.525	40
Gas GT	400	35	80	4	0.525	40
Hydro	2500	100	region specific	2	0	80
Biomass	2000	42	80	4	2.89	40
Intraday storage	1500	80	100	0.5	0	80
Interday storage	2500	70	100	1	0	20

Table A.3. Fuel costs in €/GJ. Source: European Commission (2014b) and own assumptions.

Year	Hard Coal	Lignite	Natural Gas	Uranium	Biomass
2010	1.8	1.0	5.4	0.5	2.5
2015	2.2	1.0	6.2	0.6	2.5
2020	2.6	1.0	6.9	0.7	2.5
2025	2.6	1.0	7.1	0.8	2.5
2030	2.7	1.0	7.3	1.0	2.5
2035	2.9	1.0	7.2	1.2	2.5
2040	3.1	1.0	7.2	1.4	2.5
2045	3.3	1.0	7.1	1.7	2.5
2050	3.5	1.0	7.0	2.0	2.5